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OPERATIONS ANALYSIS TECHNICAL

MEMORANDUM NO. 5

Parts I and II of Three Parts

TECHNIQUES FOR FIELD ANALYSIS OF FIGHTER RETICLE CAMERA FILM

by

ROBERT A. PORTER
Chief, Operations Analysis Division
Deputy for Operations, Hq APGC

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Operations Analysis Division
Deputy for Operations
Headquarters, Air Proving Ground Command
Eglin AF Base, Florida

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OPERATIONS ANALYSIS TECHNICAL MEMORANDUM NO. 5

SUBJECT: Techniques for Field Analysis of Fighter Reticle Camera Film

SUMMARY

This memorandum is intended to provide methods of analysis of fighter reticle camera film suitable for use by units in the field. The techniques presented do not have the accuracies required, or the breadth of application necessary for engineering, laboratory, or proving ground analyses. The types of analyses presented are:

a. Calculation of Range and Angle Off.

b. Determination of Tracking Accuracy.

c. Estimation of Number of Hi , Kills, Probable Kills, and Damages in Firing Passes.

The Calculations of Range and Angle Off are presented in Part I. The Determination of Tracking Accuracy is presented in Part II. The Estimation of Hits and Kills is presented in Part III. Part III has a security classification of SECRET and is bound separately.

PART I

CALCULATIONS OF RANGE AND ANGLE OFF

1. This part is devoted to the determination of ranges and angles off from film obtained during camera firing passes at aerial targets. The techniques apply to either reticle camera installations or GSAP camera installations.

2. It is assumed that the camera installed in the fighter was the standard 16mm GSAP camera, with a 1 3/8" focal length lens. For analysis of the film, any 16mm projector will suffice, but a magnification of 72.73 should be specified. This magnification presents the screen scale of 1 inch = 10 mils. The W-2 assessor is convenient, since the scale is already established. With the W-2 assessor, the proper scale may be obtained by adjusting the distance from the projector to the screen until the projected frame dimensions are 30.1 inches x 21.3 inches. This distance will be found to be about 100 inches, or 8 feet 4 inches.

3. a. The following measurements will be made of the projection of the target on the screen:

(1) The distance from wing tip to wing tip (or from tip tank to tip tank in aircraft so equipped). This distance will be called "S".

(2) The distance from left wing tip to the center of the tail. This distance will be called "L". The precise definition of what is meant by "the center of the tail" will be varied with specific aircraft; it is the center of the tailpipe on single engine jet fighters, the point of the tailcone on conventional aircraft, and the center of the tailplane on aircraft with boom-type empennage.

(3) The distance from the right wing tip to the center of the tail. This will be called "R".

b. For making measurements on the screen it will be convenient to use a ruler marked-off in fiftieths of an inch. One fiftieth of an inch is approximately the accuracy to which measurements can be taken from the screen image. In addition, subsequent calculations require that the readings be expressed in decimal form, rather than in inches and fractions. The conversion of readings in fiftieths of an inch to decimal form is a simple process. The procedure is to multiply the number of fiftieths by two, and then point off two places. As an example, suppose that a measurement is 39 fiftieths of an inch. Two times 39 is 78. Pointing off two places gives .78 inches. Similarly, if the reading had been 2 $\frac{39}{50}$ inches, the decimal form would have been 2.78 inches.

c. The three points involved in the measurements--the two wing tips and the center of the tail--form a triangle; or, in some special cases, all three lie on a straight line. This fact may be used as a rough check on the measurements. If the three points do not lie on a straight line, the smallest two measurements added together should be larger than the largest measurement. If the points lie on a straight line, the smallest two measurements added together should be exactly equal to the largest measurement. If these conditions are not satisfied, a remeasurement is required.

4. a. The next step in calculation is to divide R by S and to divide L by S. The results of these two divisions will be called, as usual, $\frac{R}{S}$ and $\frac{L}{S}$ respectively.

b. The ratios, $\frac{R}{S}$ and $\frac{L}{S}$, should, in general, be calculated to two decimal places to avoid large rounding-off errors in subsequent calculations. For small values of the ratios (say, less than one), a third decimal place can be used, and will improve the accuracy of the final result.

c. The ratios may be calculated, of course, by ordinary hand long division; however, this method is laborious when large numbers of ratios are to be taken. A slide rule will get the ratios much more easily for those who are familiar with its use.

5. a. In addition to the quantities already mentioned, it will be necessary to determine another quantity called "q". This is done by means of Figure 1.

b. Figure 1 will be used twice--once with R and S, and once with L and S. The result of using R and S will be called q_R; the result when using L and S will be q_L.

c. To be specific, instructions on the use of Figure 1 will be given for the determination of q_R. The steps to be taken, for either case, are as follows:

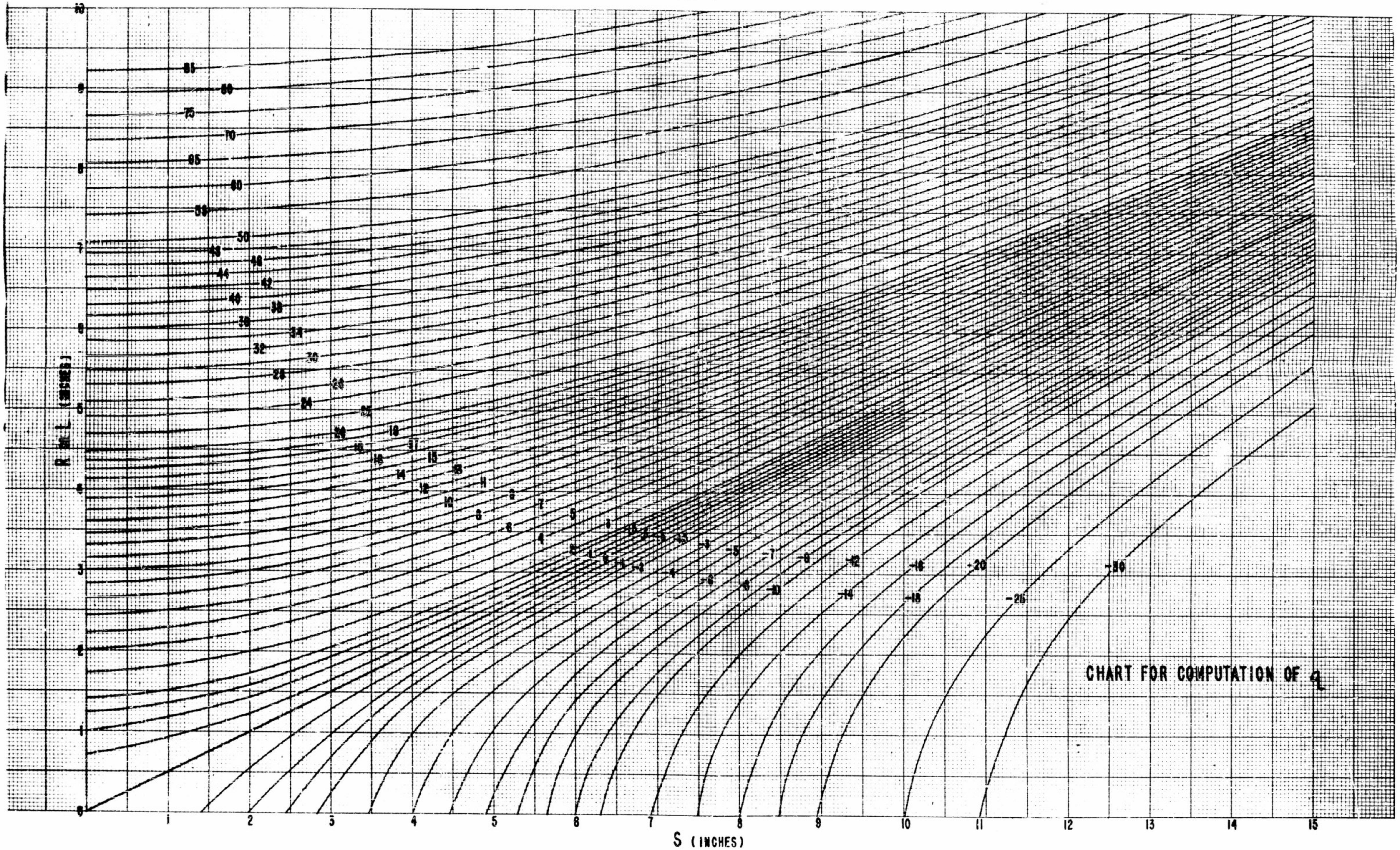
(1) Locate the vertical line corresponding to the value of S read from the screen by reading along the scale at the bottom of the chart.

(2) Locate the horizontal line corresponding to the value of R read from the screen by reading up the scale on the left hand side of the chart.

(3) Locate the point on the chart where the horizontal and vertical lines intersect.

(4) Read off q_R by referring to the values of the curved lines on the chart between which the point of intersection falls. This may be done with sufficient accuracy by visual interpolation between the two adjoining lines. It should be noticed that if the

FIG 1



point of intersection is in the lower right hand corner of the chart, below the straight line slanting upward diagonally from the lower left hand of the chart, the value of q_R is negative, or minus; if the point of intersection is in the upper left hand portion of the chart above the straight line, q_R will be positive, or plus.

d. The value q will be obtained by adding together the values of q_R and q_L. If one or the other of these two values is negative, it will, of course, be substracted. As a check on the work, it can be said that in no case where the work has been correctly carried out will both q_R and q_L be negative; and in every case where one of the two values is negative the other (positive) value will be numerically larger so that the net result will always be positive or plus.

6. a. The first quantity to be calculated is "angle off." Angle-off is defined as the angle between the center line of the fuselage of the target and the line from the attacking fighter to the target. Zero degrees angle-off corresponds to an attack directly on the tail of the target--the six o'clock level position. It should be understood that angle-off so defined is neither the azimuth (horizontal) angle or the elevation angle, but a combination of both. That is, an attacking aircraft can be at 30° angle off by being at six o'clock either high or low; it can also be at 30° angle off by being level at seven o'clock or five o'clock. More commonly, an angle-off will be composed of some deflection in both azimuth and elevation. In other words, attacks are seldom exactly level or exactly at six o'clock.

b. In order to determine angle-off, it is necessary to use the angle-off chart appropriate to the target aircraft, that is, the aircraft of which the picture is taken. These angle-off charts are labeled under the assumption that the attack is being made from the target's right side. Since the aircraft is symmetrical, however, these same charts may be used when the attack is made from the aircraft's left side by interchanging the values of $\frac{L}{S}$ and $\frac{R}{S}$. These values themselves will tell whether or not reversal is necessary. The smaller of the two quantities will always be used as the ordinate (read off the scale on the left side of the chart), and the larger of the two quantities will always be used as the abscissa (read off the scale along the bottom of the chart). If this method is used, it will never be necessary to distinguish between attacks made from the right and from the left sides, and the correct value of angle off can be read directly from the chart.

c. Each angle off chart is in two parts: a large scale chart for use when both the quantities $\frac{L}{S}$ and $\frac{R}{S}$ are less than one, and a small scale chart for use when one or both of the values of $\frac{R}{S}$ and $\frac{L}{S}$ is greater than one. There is no difference in the use of either of the two sections of the chart. The division into sections was merely for convenience in reproduction.

d. In using the chart, the horizontal line corresponding to the smaller of the two values of $\frac{R}{S}$ and $\frac{L}{S}$ is found by reading along the scale on the left margin. The vertical line corresponding to the larger

of the values $\frac{R}{S}$ and $\frac{L}{S}$ is found by reading along the scale at the bottom of the chart. Values which do not appear as lines marked on the chart may be found by interpolation in both instances.

e. The intersection of the horizontal line and the vertical line will be a point on the chart. When this point has been found the angle off may be determined by comparison with the two adjacent curved lines which represent 3° intervals in angle off. The angle off may be estimated to the nearest degree by visual interpolation between the two adjacent lines. This value will be recorded.

7. a. The final step in the computation is the determination of the range. This will require the angle-off, found in paragraph 6 above, and q, found in paragraph 5 above.

b. In the range graph for the appropriate target aircraft, a vertical line corresponding to angle-off will be located reading along the scale at the bottom of the chart.

c. The horizontal line corresponding to q will be found by reading up the scale along the side of the chart. The use of this scale on the left hand side of the chart requires caution, since it is "logarithmic." The principal difference between logarithmic paper and ordinary graph paper is that the difference in values between the successive lines on the graph is not constant. At the top of the graph the difference between two successive lines is 50; at the bottom of the graph the difference between two successive lines is .005. Care must be taken both in locating the two lines between which the given value of q lies, and also in interpolating between those two lines.

d. When the correct horizontal and vertical lines have been located their point of intersection is found. The range in feet is read off by interpolating between the two adjoining curved lines as in previous graphs.

8. a. It will be convenient to have data sheets set up on which to record the readings and the intermediate steps of the range and angle-off computations. Figure 2 is a suggested form for a computation sheet. This sheet has space for eight range and angle-off computations. The first column, labeled "Frame Identification," may be used to record such information as pilot's name, aircraft number, mission number, pass number, or other appropriate identifying information. The balance of the columns are for the film readings, the intermediate computations, and the final results.

b. Example 1 is worked out in the first block of Figure 2. In this example it is assumed that the diagram appearing in the angle-off graph for the F-86F is the image which is found on the screen.

(1) The distance as measured from right wing tip to tail is about 65 fiftieths of an inch. Multiplying 65 by two, and pointing off two places, we enter 1.30 opposite R in the column headed "film readings."

Figure 2

RANGE AND ANGLE OFF COMPUTATION SHEET

Frame Identification	Film Readings	Ratios	Computation of q	Angle Off	Range
Example 1 (F-86F)	R = 1.30	$\frac{R}{S}$ = 1.07	q_R = 1.32	64°	1700ft
	L = .56	$\frac{L}{S}$ = .46	q_L = -.06		
	S = 1.22		q = 1.26		
Example 2 (F-84G)	R = 1.66	$\frac{R}{S}$ = .69	q_R = 1.32	37°	1500 ft
	L = 1.22	$\frac{L}{S}$ = .51	q_L = .05		
	S = 2.40		q = 1.37		
Example 3 (B-50)	R = 2.74	$\frac{R}{S}$ = .49	q_R = -.28	14°	2800 ft
	L = 2.94	$\frac{L}{S}$ = .53	q_L = .86		
	S = 5.58		q = .58		
	R =	$\frac{R}{S}$ =	q_R =		
	L =	$\frac{L}{S}$ =	q_L =		
	S =		q =		
	R =	$\frac{R}{S}$ =	q_R =		
	L =	$\frac{L}{S}$ =	q_L =		
	S =		q =		
	R =	$\frac{R}{S}$ =	q_R =		
	L =	$\frac{L}{S}$ =	q_L =		
	S =		q =		
	R =	$\frac{R}{S}$ =	q_R =		
	L =	$\frac{L}{S}$ =	q_L =		
	S =		q		
	R =	$\frac{R}{S}$ =	q_R =		
	L =	$\frac{L}{S}$ =	q_L =		
	S =		q =		

(2) Similarly we measure L, from the left wing tip to the tail, as 28 fiftieths of an inch, and S, the distance between the two wing tips, as 61 fiftieths of an inch. Accordingly we enter L on the sheet as .56, and S as 1.22.

(3) In the next column on the work sheet headed "ratios," we enter the ratios $\frac{R}{S}$ and $\frac{L}{S}$. $\frac{R}{S}$ is 1.30 divided by 1.22, or 1.07. $\frac{L}{S}$ is .56 divided by 1.22, or .46.

(4) The next step is to compute q. Using Figure 1, we find the line corresponding to 1.30 (R) by reading along the scale at the left hand side of the chart. We find the vertical line corresponding to 1.22 (S) by reading along the scale at the bottom of the chart. The point of intersection of these two lines lies between the curved lines labeled q = 1 and q = 1.5. By visual estimation we interpolate q_R to be 1.32, and enter the result on the work sheet.

(5) To find q_L, the same vertical line corresponding to S = 1.22 will be used, but along the scale at the left of the chart we will locate the horizontal line corresponding to .56 (L). The intersection of these two lines lies between the straight line for q = 0 and the curved line for q = .5. By interpolation we estimate q_R = -.06.

(6) Adding q_R to q_L (remembering that q_L was negative), we obtain q = 1.26.

(7) $\frac{L}{S}$ is smaller than $\frac{R}{S}$ so the angle-off graph will be used as labeled. On the angle-off graph it will found that the section on the right hand side of the page must be used because $\frac{R}{S}$ is greater than 1. The horizontal line corresponding to $\frac{L}{S}$ = .46 is found by reading along the graph at the left of the right hand section of the chart. The vertical line corresponding to $\frac{R}{S}$ = 1.07 is located by reading the scale along the bottom of the chart, interpolating between the lines corresponding to 1.05 and 1.10. The point of intersection of these two lines will be found to lie between the curved lines labeled 63° and 66°, a little closer to the 63° line. As a consequence we write on the working sheet 64° under "angle-off."

(8) Proceeding to the range graph for the F-86F we find q = 1.26 by reading along the logarithmic scale at the left hand side of the graph. Lines are labeled 1 and 2, and the intermediate line unlabeled between

them corresponds to 1.5. Consequently the horizontal line corresponding to q = 1.26 lies about midway between the line labeled 1 and the unlabeled line above it, slightly closer to the latter. The vertical line corresponding to an angle off of 64° is found by reading along the scale at the bottom of the graph. The intersection of these two lines will be found to lie between the curved lines labeled 1500 feet and 1800 feet, a little closer to the latter. As a consequence, we enter under "range" 1700 feet.

c. Examples 2 and 3, applying to an F-84G and a B-50 respectively, are presented in the second and third blocks of Figure 2. The "film readings" given for these examples are imaginary, and are used only for illustration. Following through these computations will give additional practice in computation of range and angle-off.

9. Range and Angle-off graphs are attached as follows:

a. F-86F (Applicable also to other models of the F-86)

b. F-84G (Applicable also to other straight-wing models of the F-84)

c. B-50 (Applicable also to B-29)

d. Meteor

e. Vampire

f. Canberra

PART II

THE DETERMINATION OF TRACKING ACCURACY

1. a. This part deals with the estimation of tracking accuracy from reticle camera film. It is not possible to determine tracking accuracy from film obtained by an ordinary GSAP camera installation.

b. It is supposed that range and angle-off have been calculated for several points in a burst by the methods of Part I.

2. a. Additional film readings are required to obtain tracking accuracy. The first step in obtaining these film readings is to separate the frames of film into the groups which constitute a "burst." A burst starts with the first frame in which the over run marker in the upper left hand corner of the film does not appear, and stops with the last frame before the over run marker appears.

b. (1) The next step is to count the total number of frames in the burst. This will be called N.

(2) The next step is to count the total number of frames in which the center of the pip is on the target. It will bear repeating that the center of the pip must be on the target, rather than the edge of the pip. At short ranges this distinction will make little difference, for the screen image of the target will be large compared to the size of the pip, and usually when the center of the pip is on the target the entire pip will also be on the target. At long ranges, however, the pip may be approximately the same size as the image of the target and appreciable differences may be introduced. At long range it may be also necessary to estimate whether the center of the pip is on the target since the image of the pip on the screen may obliterate part of the image of the target. The number of the frames in which the center of the pip is on the target will be called n.

3. a. The first step in computation will be to divide n by N. This ratio will be called p, the percentage of frames with center of pip on the target.

b. The next step is to determine the average range and average angle-off of the burst. It is not extremely important how this average is obtained. If a number of range and angle-off determinations have been made during the burst, an observation near the middle of the burst may be used as the average. If the range and angle-off at the opening of the burst and at the closing of the burst have been computed, the ordinary arithmetic average of the opening and closing ranges, and opening and closing angles-off, will be adequate.

4. The area presented by any aircraft varies with the type of aircraft, and also with the angle-off from which it is viewed. In addition, the tracking

problem presented to the pilot is an angular problem--that is, his presentation is in mils, rather than in feet. It is therefore important to find out the "angular area" presented to the pilot by the target aircraft. The conversion from area of target in square feet to area in angle measure involves the range. Angular Area Tables are presented for each target aircraft. In these Angular Area Tables the average range is located by reading down in the left hand column. The average angle off is located by reading across the top. For most purposes the nearest value to the average range and average angle off will be adequate. For greater accuracies, it is possible to interpolate in the Angular Area Tables.

5. a. Tracking error is determined by use of Figure 3. The quantities necessary for the use of Figure 3 are p (found in paragraph 3a above), and the angular area of the aircraft, (found in paragraph 4 above). The result read from Figure 3 will be the tracking accuracy in mils. The definition of this tracking accuracy is the one usually used, and is more precisely defined as the standard deviation of the bivariate normal density distribution of tracking errors. It is beyond the scope of this memorandum to go into detail about the technical definition, but it may be stated that in most cases approximately 40% of the time the center of the pip will be within one standard deviation of the center of the target.

b. In the use of Figure 3, the angular area is read in the scale along the left hand side of the chart, and the corresponding horizontal line determined. This scale is "logarithmic", and is used like the similar scale on the Range Graphs, described in Part I. p, the percentage of frames with center of pip on the target, is read in the scale along the bottom of the chart. The vertical line corresponding to the observed value of p, and the horizontal line corresponding to the observed value of the angular area, intersect in a point. This point will be used, as in the other graphs, for the reading of tracking accuracy from the curved lines of the chart.

6. Example:

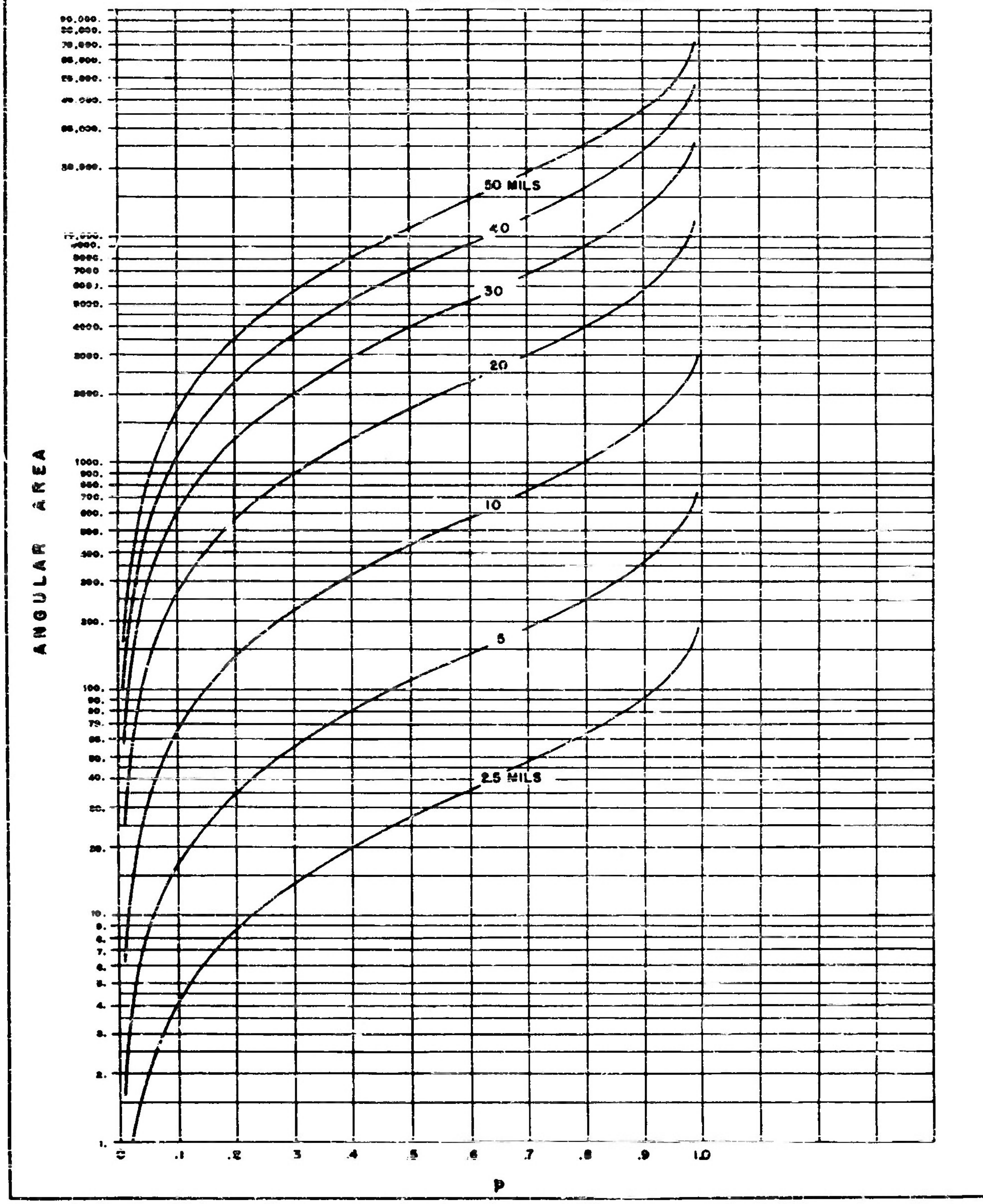
a. Suppose the following situation:

Target aircraft	=	F-86F
Opening Range	=	2600 feet
Closing Range	=	2200 feet
Opening Angle-Off	=	19°
Closing Angle-Off	=	11°
Number of Frames in Burst	=	63

Number of Frames with Center of Pip on Target = 17

FIG. 3

TRACKING ACCURACY GRAPH



b. In this situation,

$$p = \frac{n}{N} = \frac{17}{63} = .27$$

$$\text{average angle off} = \frac{19^\circ + 11^\circ}{2} = 15^\circ$$

$$\text{average range} = \frac{2600 + 2200}{2} = 2400 \text{ feet.}$$

c. From the Angular Area Table for the F-86F, using the average angle-off of 15°, and an average range of 2400 feet, we obtain (by interpolation) 44 as the angular area.

d. By use of Figure 3, with p = .27, and angular area = 44, we estimate tracking accuracy as 4 mils.

7. Attached at the end of this part are Angular Area Tables for the same aircraft as were listed in Part I, paragraph 9.

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ANGULAR AREA TABLE

F-86F

Average Range (Feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	2912	3584	5488	8192	11,920	13,680	15,440
500	728	896	1372	2048	2980	3420	3860
1000	182	224	343	512	745	855	965
2000	46	56	86	128	186	214	241
3000	20	25	38	57	83	95	107
4000	11	14	21	32	47	53	60
5000	7	9	14	20	30	34	39
6000	5	6	10	14	21	24	27
7000	4	5	7	10	15	17	20
8000	3	3	5	8	12	13	15
9000	2	3	4	6	9	11	12

ANGULAR AREA TABLE

F-84G

Average Range (Feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	2368	2944	4592	6928	9440	11,664	13,200
500	592	736	1148	1732	2360	2916	3300
1000	148	184	287	433	590	729	825
2000	37	46	72	108	148	182	206
3000	16	20	32	48	66	81	92
4000	9	12	18	27	37	46	52
5000	6	7	11	17	24	29	33
6000	4	5	8	12	16	20	23
7000	3	4	6	9	12	15	17
8000	2	3	4	7	9	11	13
9000	2	2	4	5	7	9	10

ANGULAR AREA TABLE

B-50

Average Range (Feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	22,512	24,928	31,776	41,152	50,736	58,144	61,616
500	5628	6232	7944	10,288	12,684	14,536	15,404
1000	1407	1558	1986	2572	3171	3634	3851
2000	352	390	497	643	793	909	963
3000	156	173	221	286	352	404	428
4000	88	97	124	161	198	227	240
5000	56	62	79	103	126	145	154
6000	39	43	55	72	88	101	107
7000	29	32	41	52	65	74	79
8000	22	24	31	40	49	57	60
9000	17	19	24	32	39	45	47

ANGULAR AREA TABLE

Meteor

Average Range (feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	2512	3168	5024	7632	10,464	12,928	14,592
500	628	792	1256	1908	2616	3232	3648
1000	157	198	314	477	654	808	912
2000	39	50	79	119	164	202	228
3000	17	22	35	53	73	90	101
4000	10	12	20	30	41	51	57
5000	6	8	13	19	26	32	36
6000	4	6	9	13	18	22	25
7000	3	4	6	10	13	16	19
8000	2	3	5	7	10	13	14
9000	2	2	4	6	8	10	11

ANGULAR AREA TABLE

Vampire

Average Range (feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	1888	2272	3376	4912	6512	7808	8528
500	472	568	844	1228	1628	1952	2132
1000	118	142	211	307	407	488	533
2000	30	36	53	77	102	122	133
3000	13	16	23	34	45	54	59
4000	7	9	13	19	25	31	33
5000	5	6	8	12	16	20	21
6000	3	4	6	9	11	14	15
7000	2	3	4	6	8	10	11
8000	2	2	3	5	6	8	8
9000	1	2	3	4	5	6	7

ANGULAR AREA TABLE

Canberra

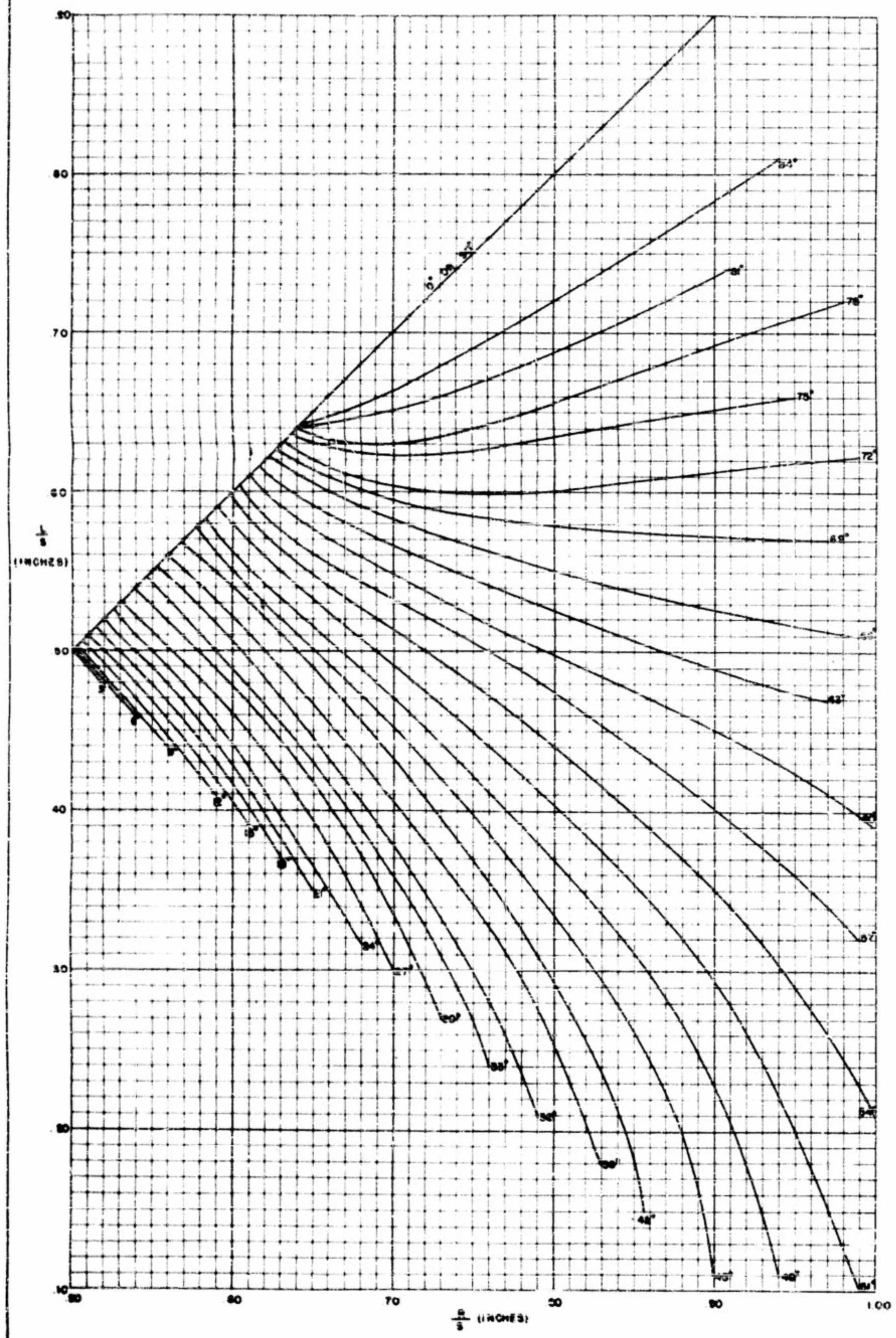
Average Range (feet)	Average Angle-Off						
	0°	15°	30°	45°	60°	75°	90°
250	5120	6384	9984	15,072	20,624	25,536	28,960
500	1280	1596	2496	3768	5156	6384	7240
1000	320	399	624	942	1289	1596	1810
2000	80	100	156	236	322	399	453
3000	36	44	69	105	143	177	201
4000	20	25	39	59	81	100	113
5000	13	16	25	38	52	64	72
6000	9	11	17	26	36	44	50
7000	7	8	13	19	26	33	37
8000	5	6	10	15	20	25	28
9000	4	5	8	12	16	20	22

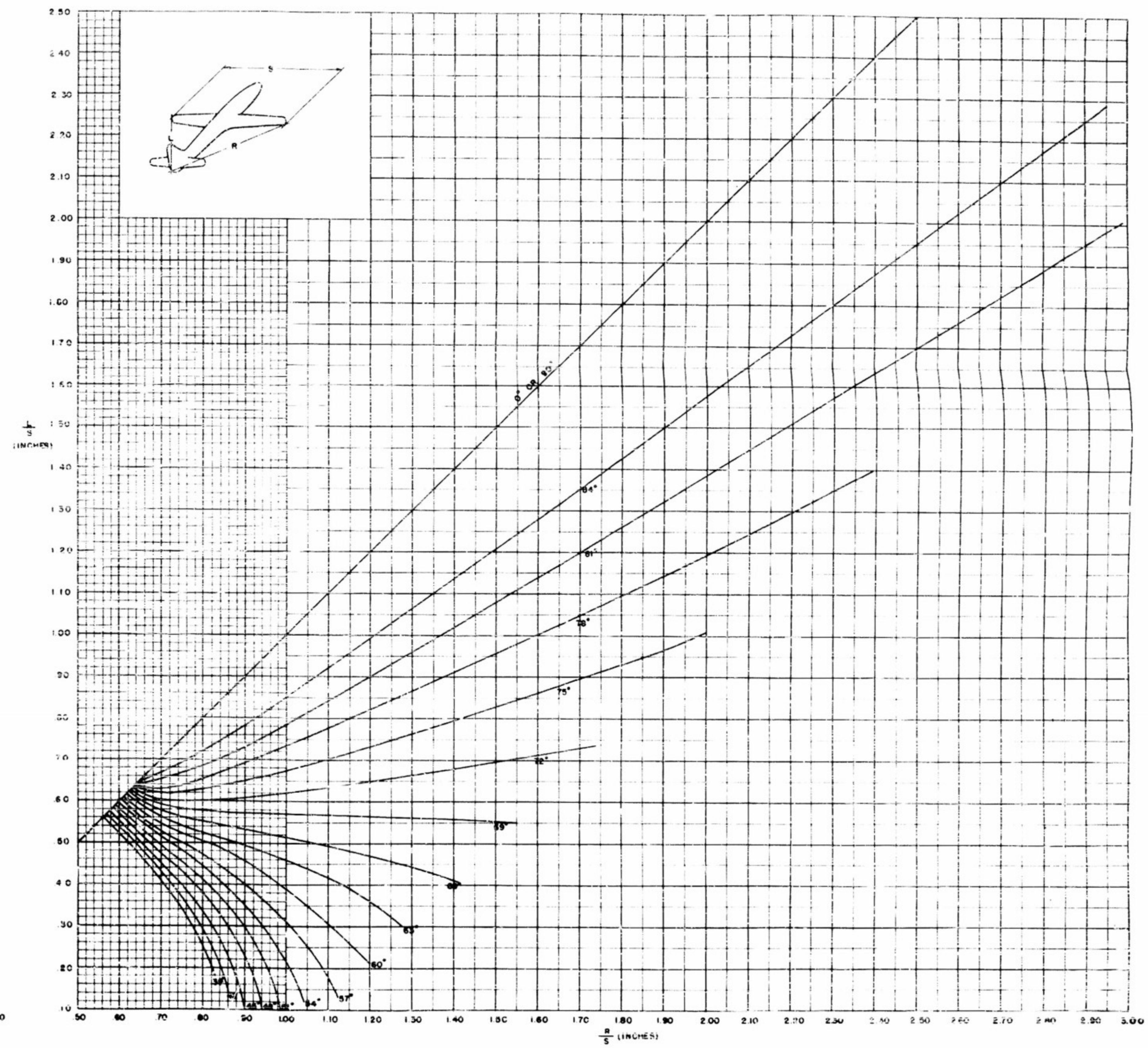
ANGULAR AREA TABLE

B-47B

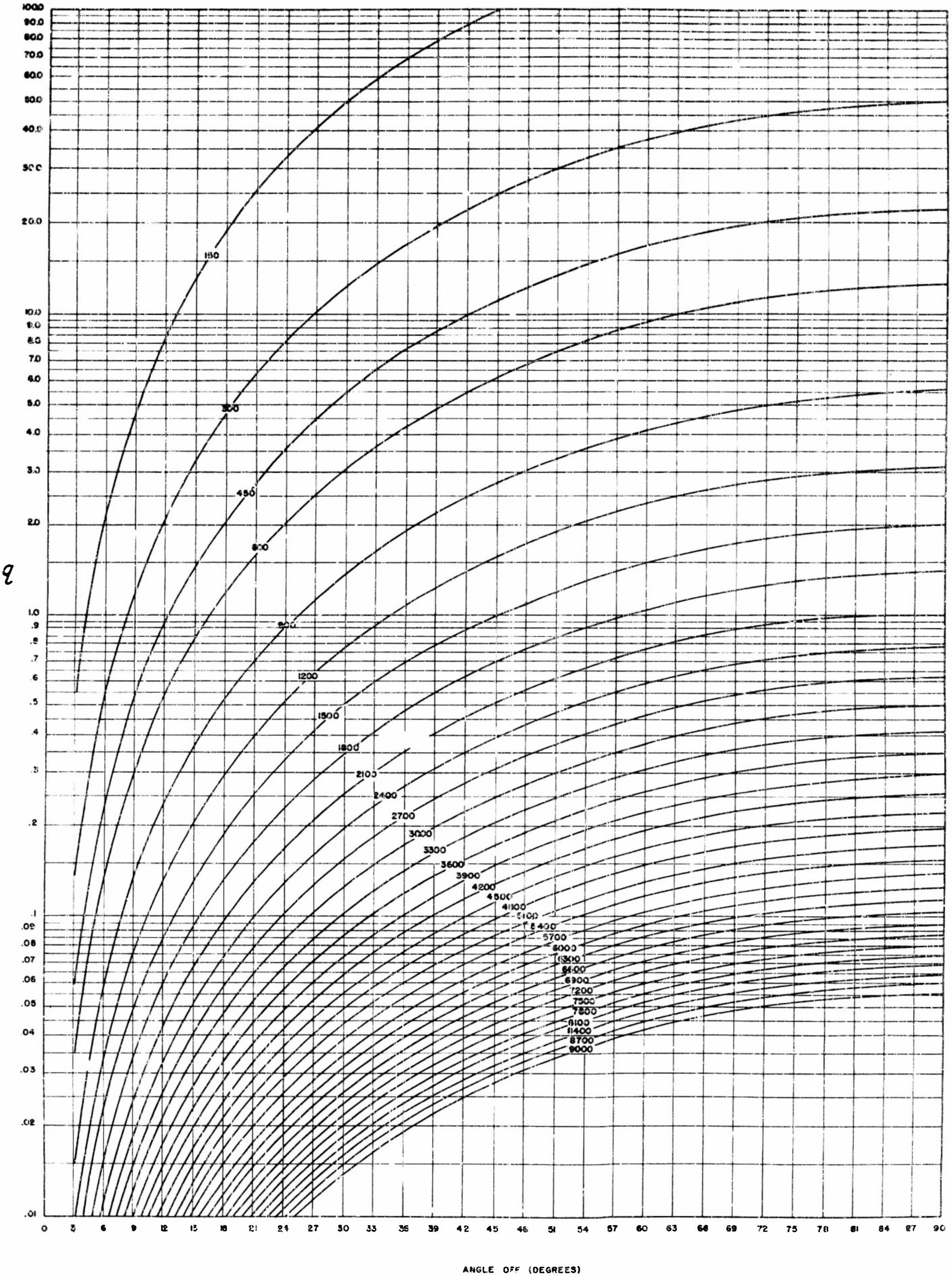
Average Range (Feet)	Average Angle-Off 0°	15°	30°	45°	60°	75°	90°
250	8336	11,824	21,760	35,856	51,328	65,152	74,992
500	2084	2956	5440	8964	12,832	16,288	18,748
1000	521	739	1360	2241	3208	4072	4687
2000	130	185	340	560	802	1018	1172
3000	58	82	151	249	356	452	521
4000	33	46	85	140	201	255	293
5000	21	30	54	90	128	163	187
6000	14	21	38	62	89	113	130
7000	11	15	28	46	65	83	96
8000	8	12	21	35	50	64	73
9000	6	9	17	28	39	50	58

F-86F ANGLE OFF GRAPH

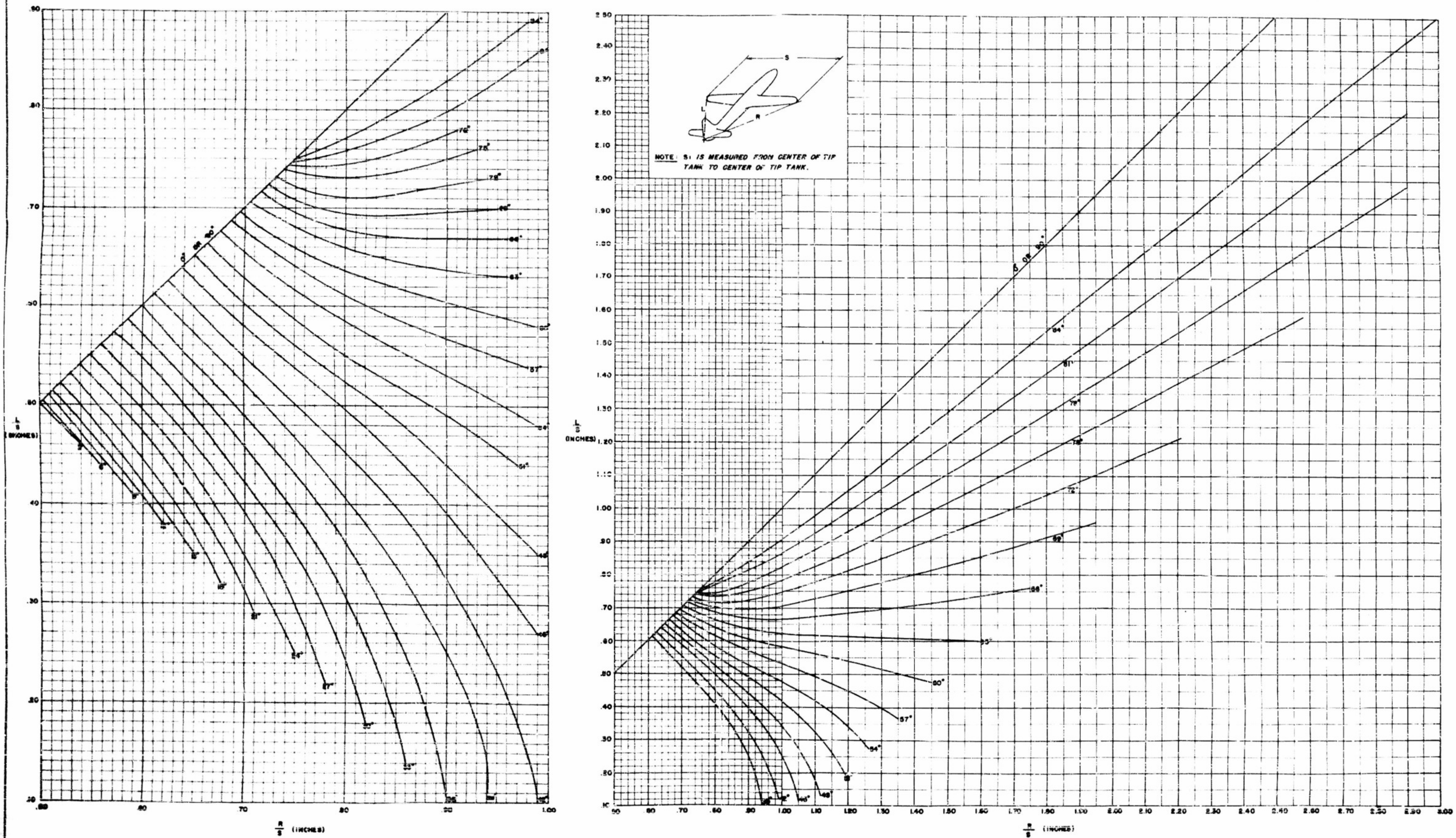




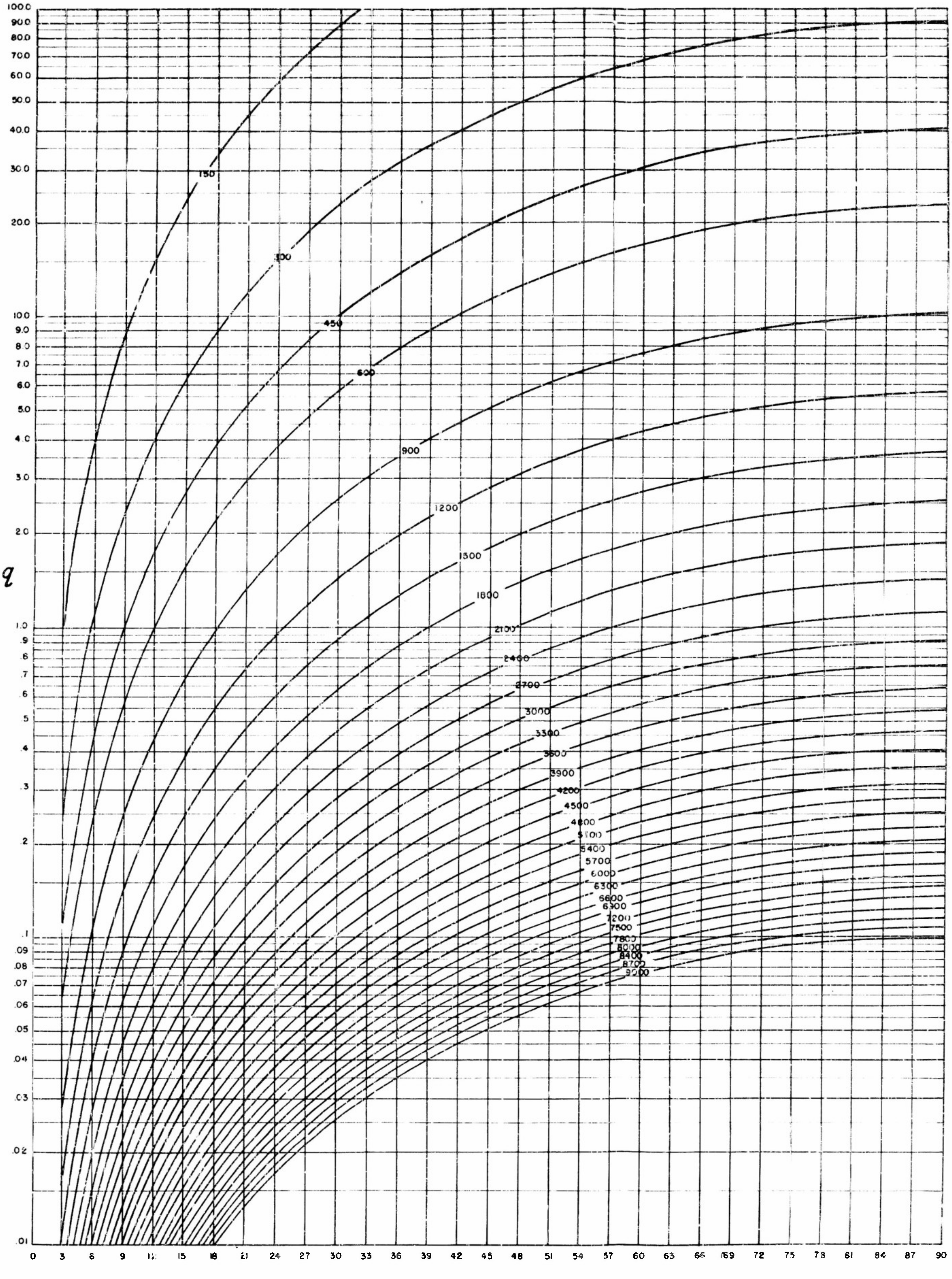
F-86 RANGE GRAPH



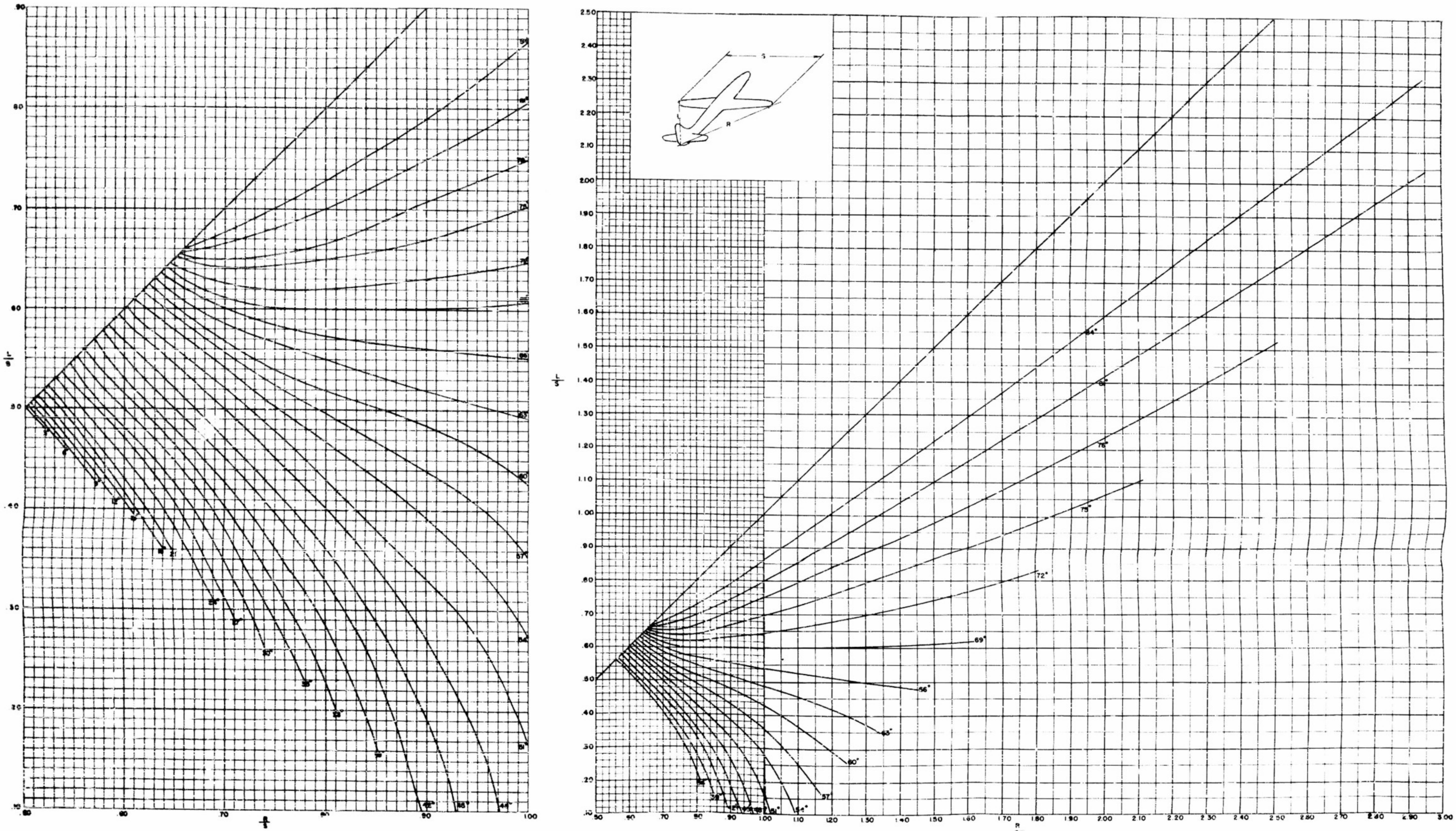
F 84 ANGLE OFF GRAPH



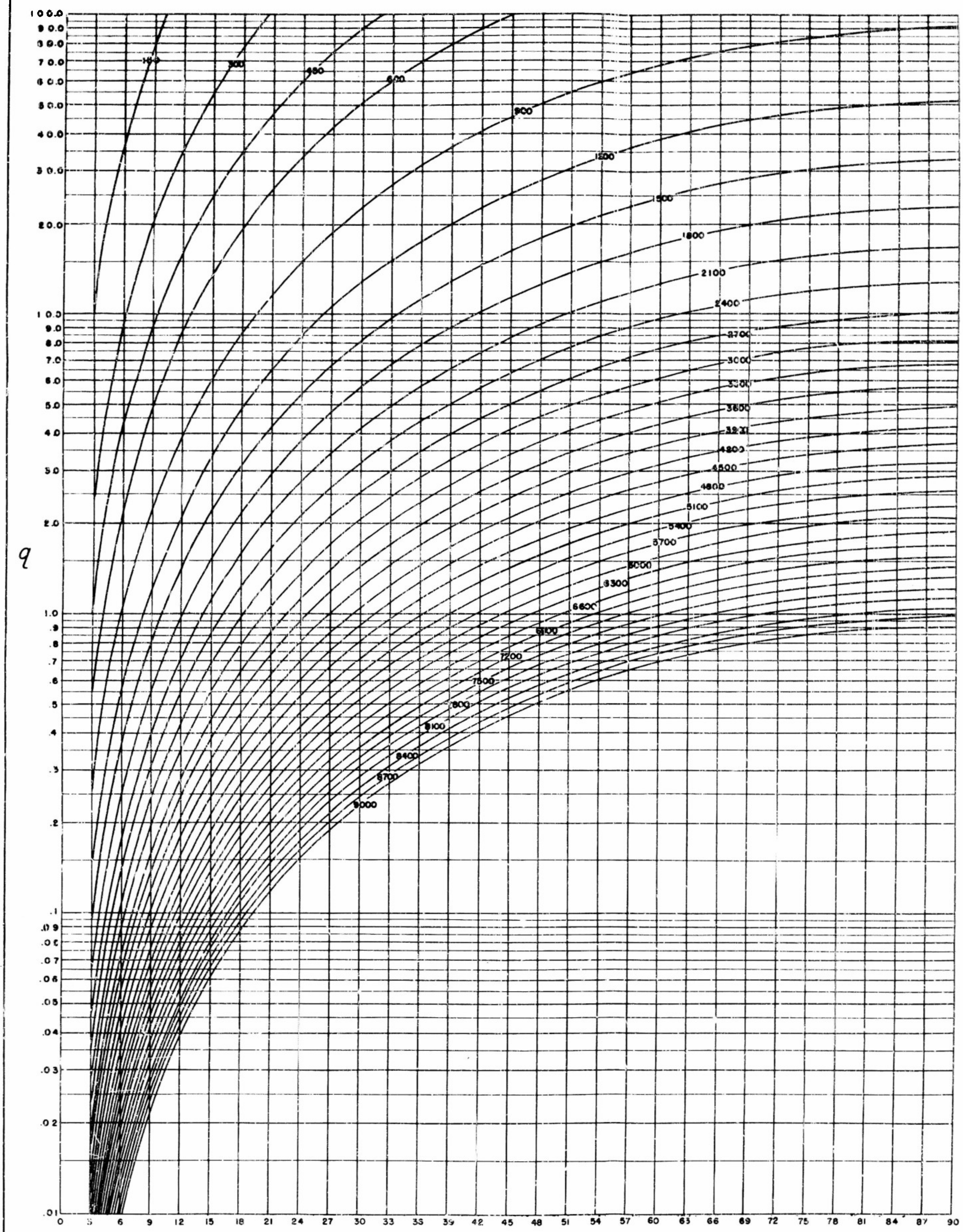
F-84 RANGE GRAPH



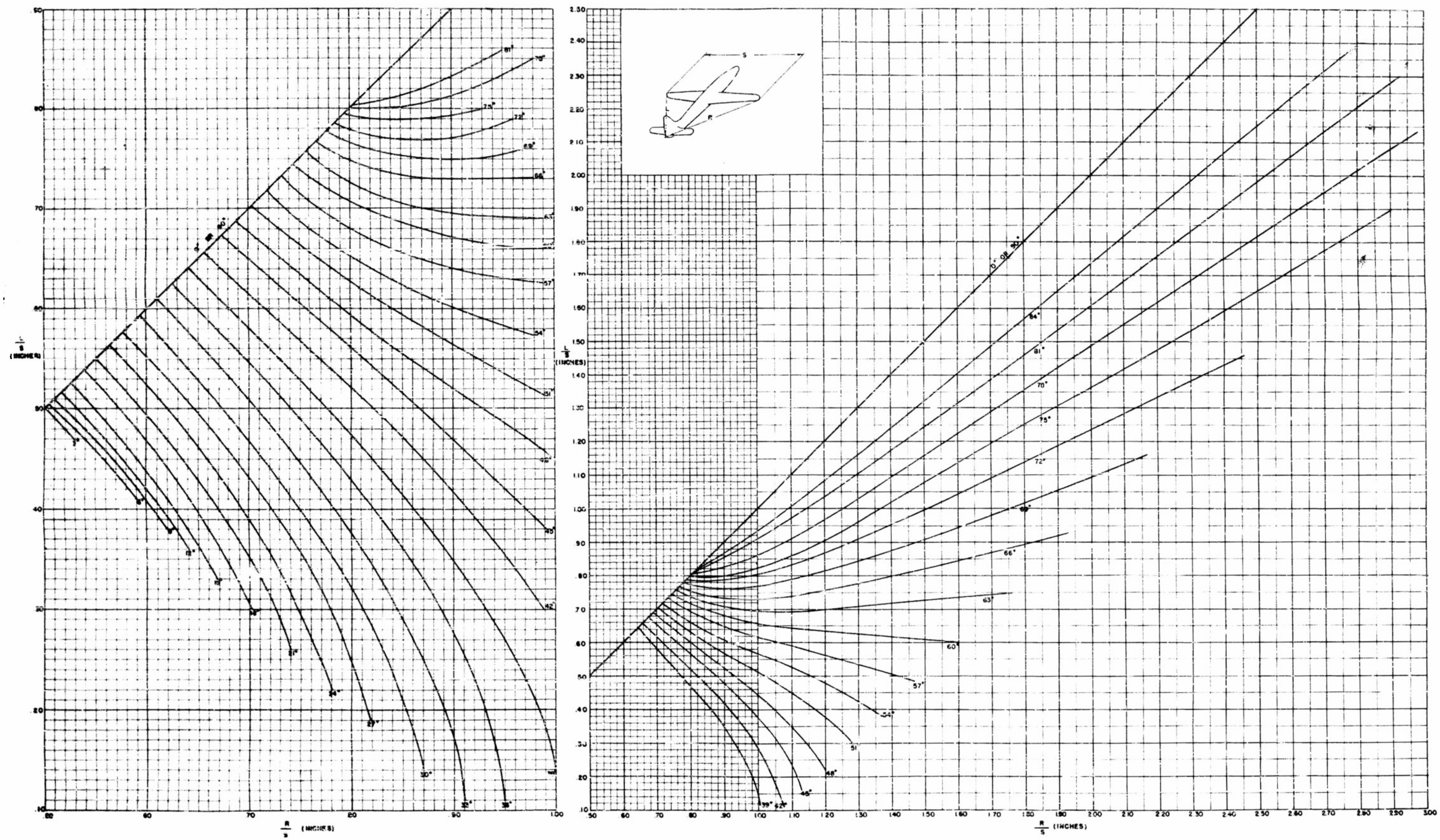
B-50 ANGLE OFF GRAPH



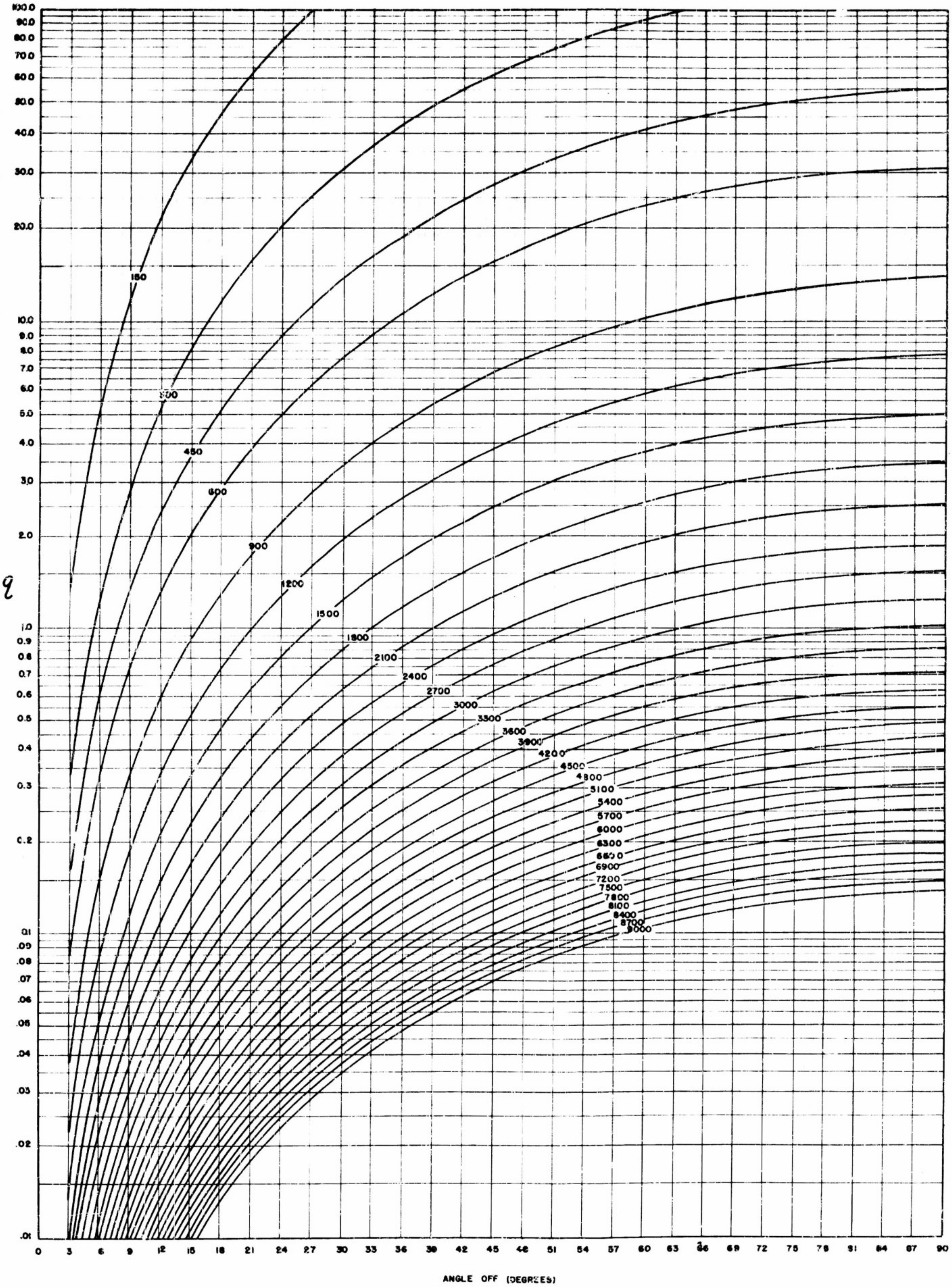
B - 50 RANGE GRAPH



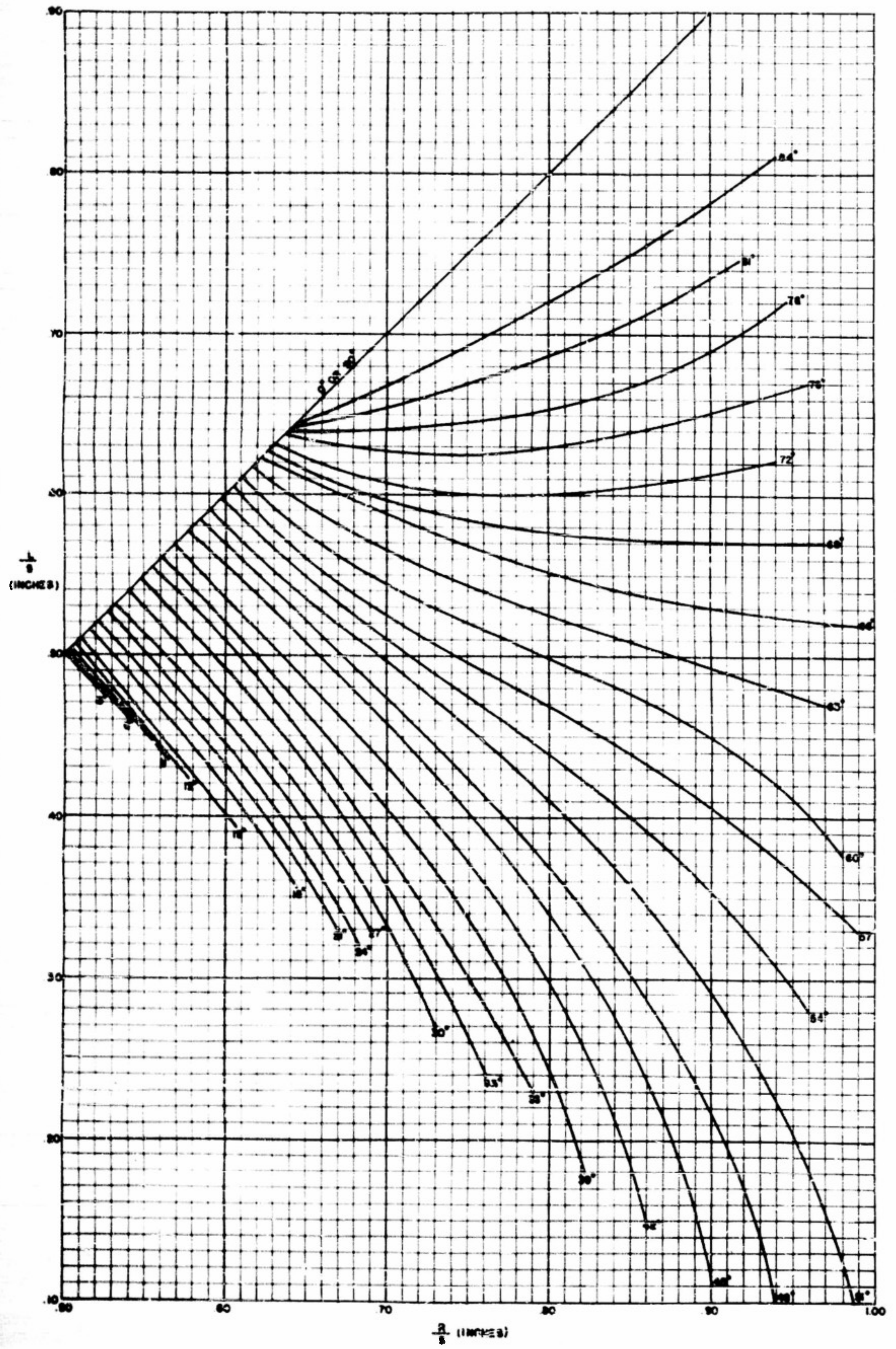
METEOR ANGLE OFF GRAPH

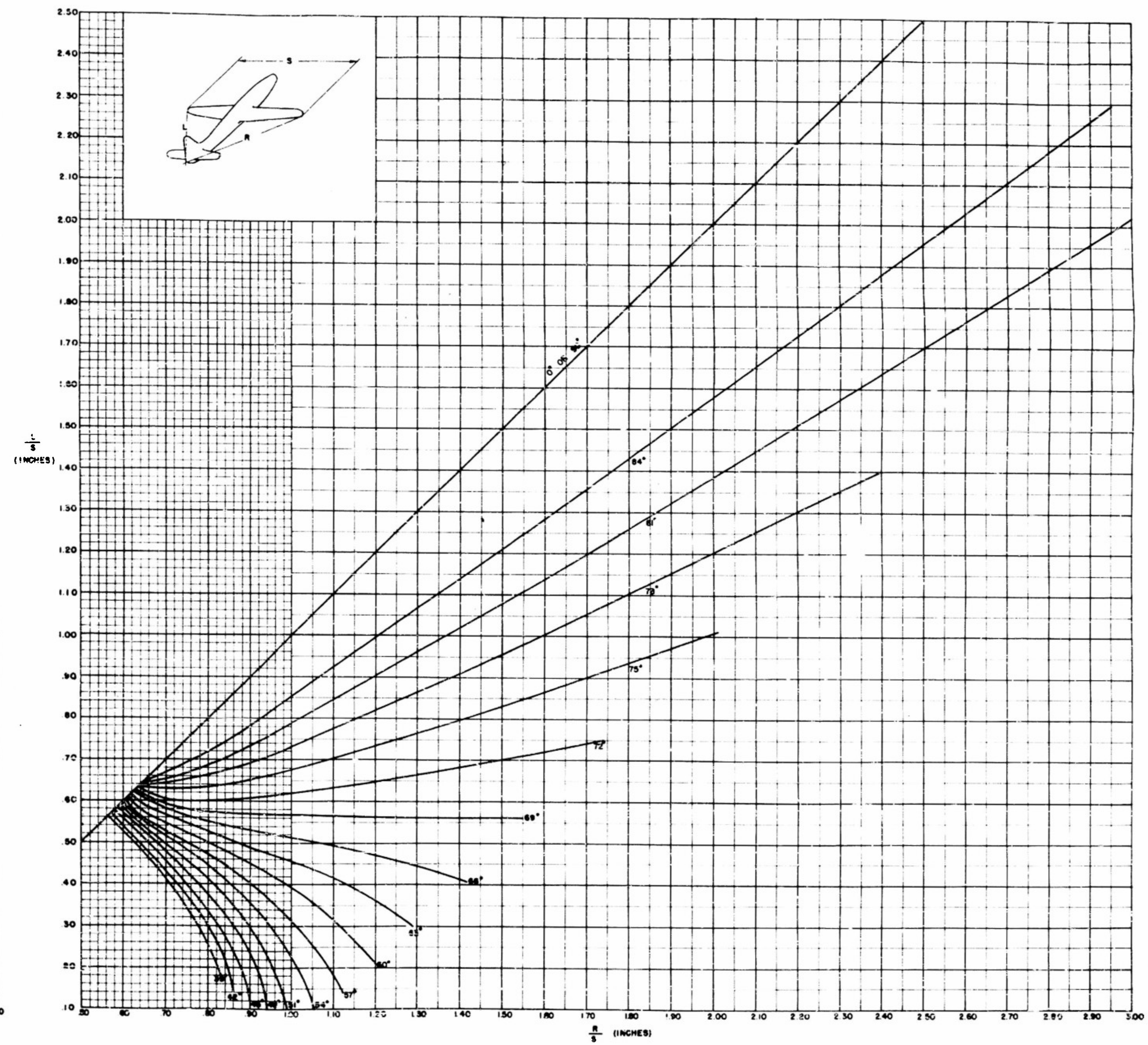


METEOR RANGE GRAPH

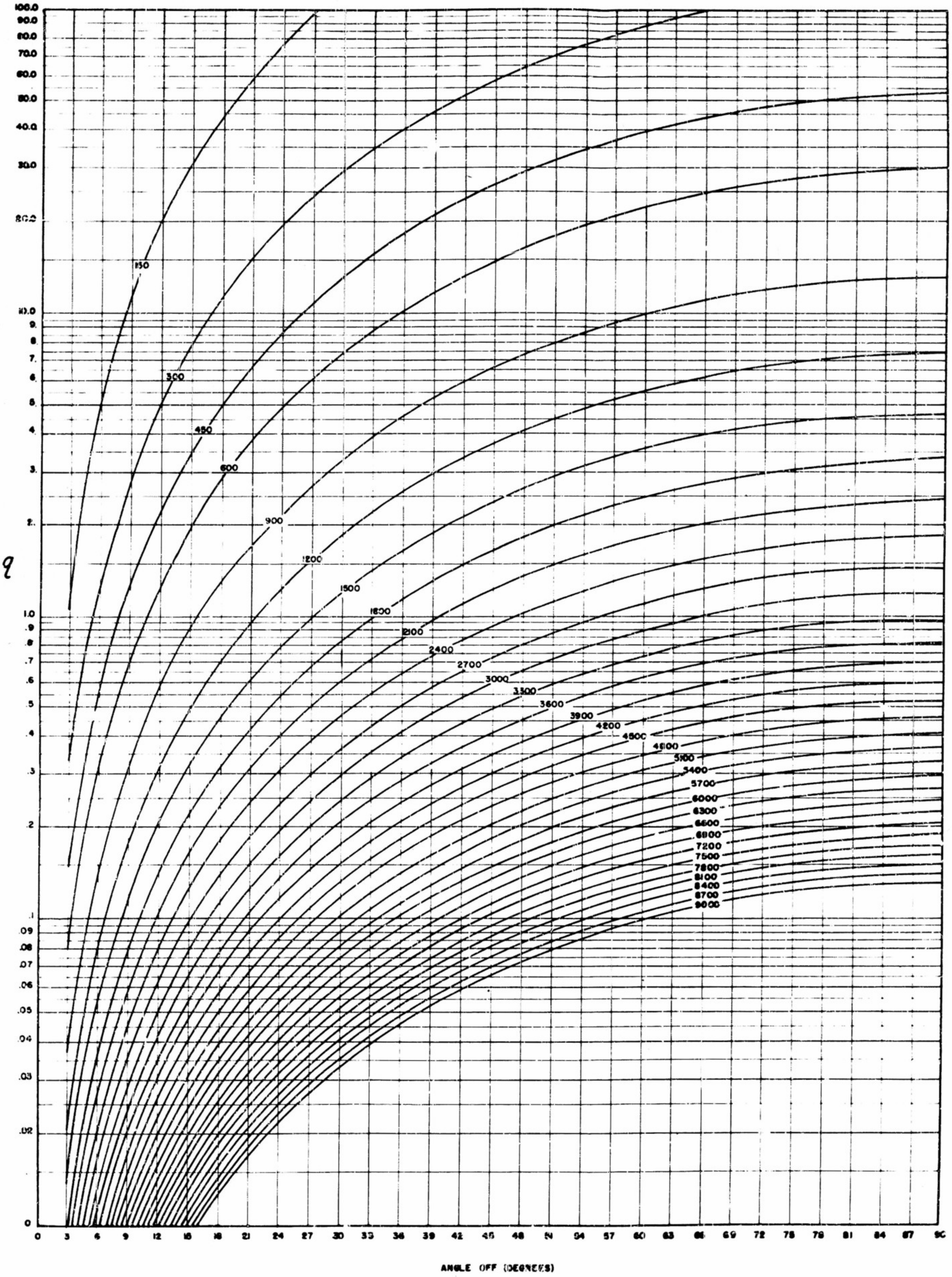


VAMPIRE ANGLE OFF GRAPH

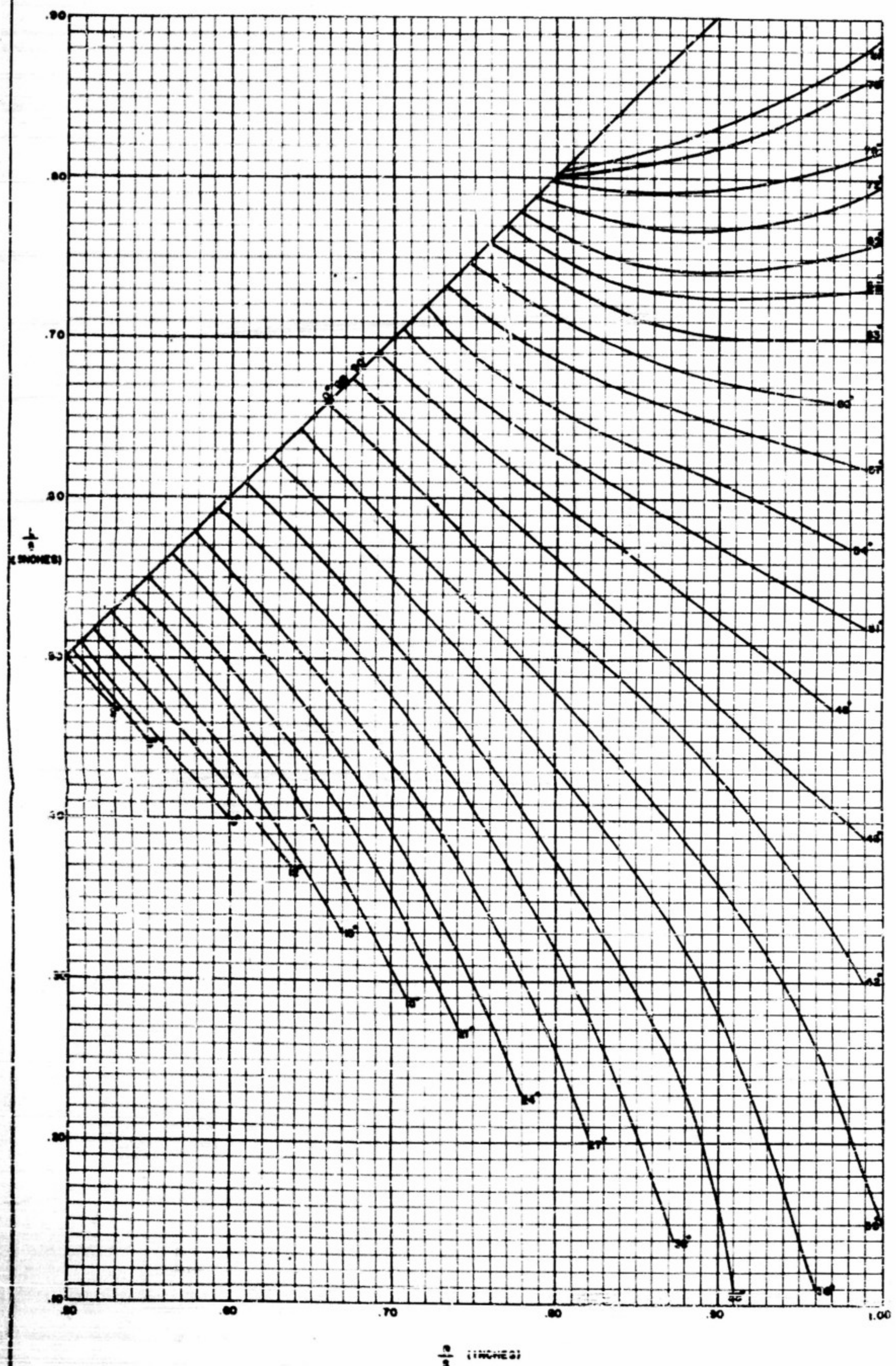


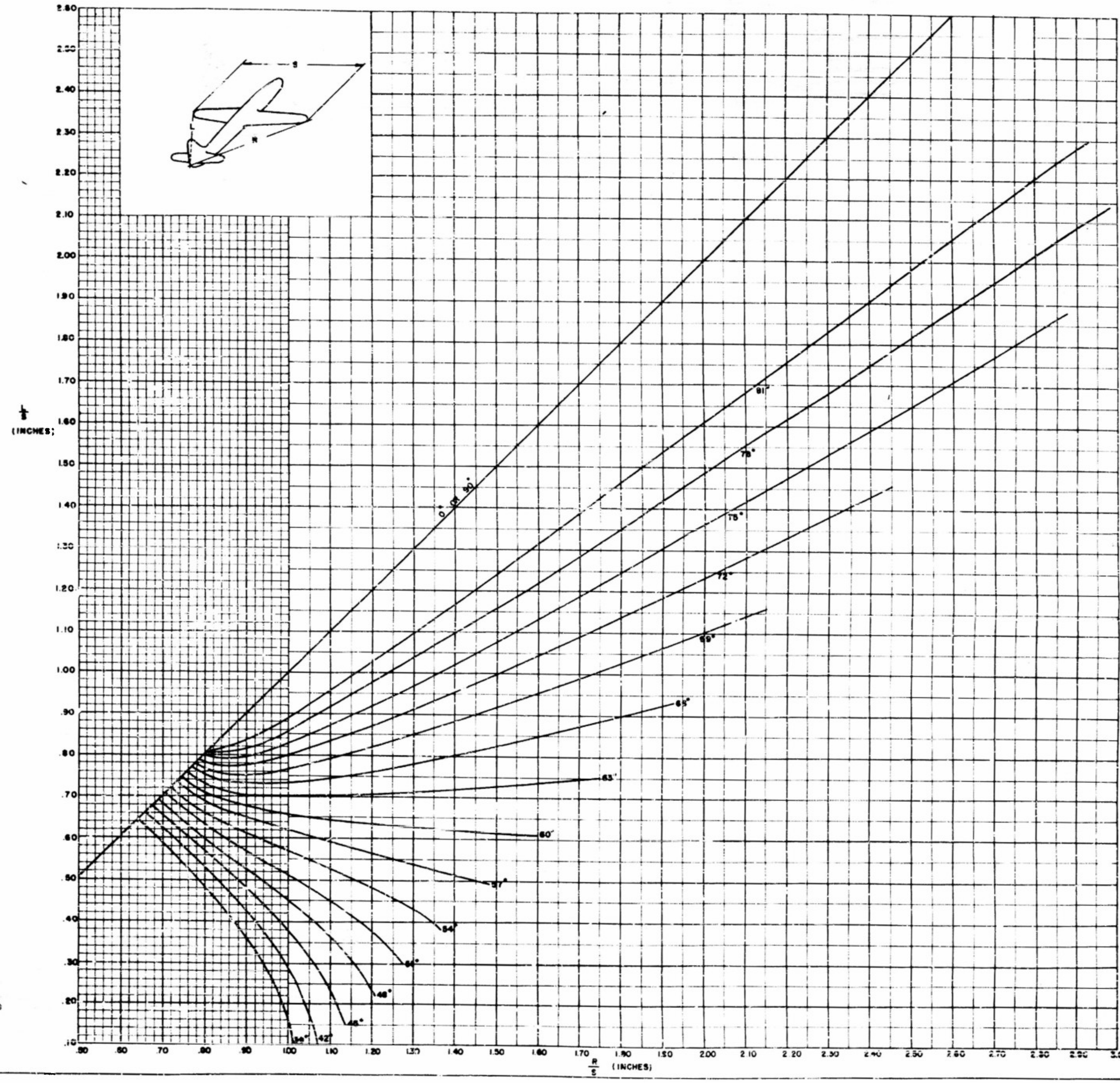


VAMPIRE RANGE GRAPH

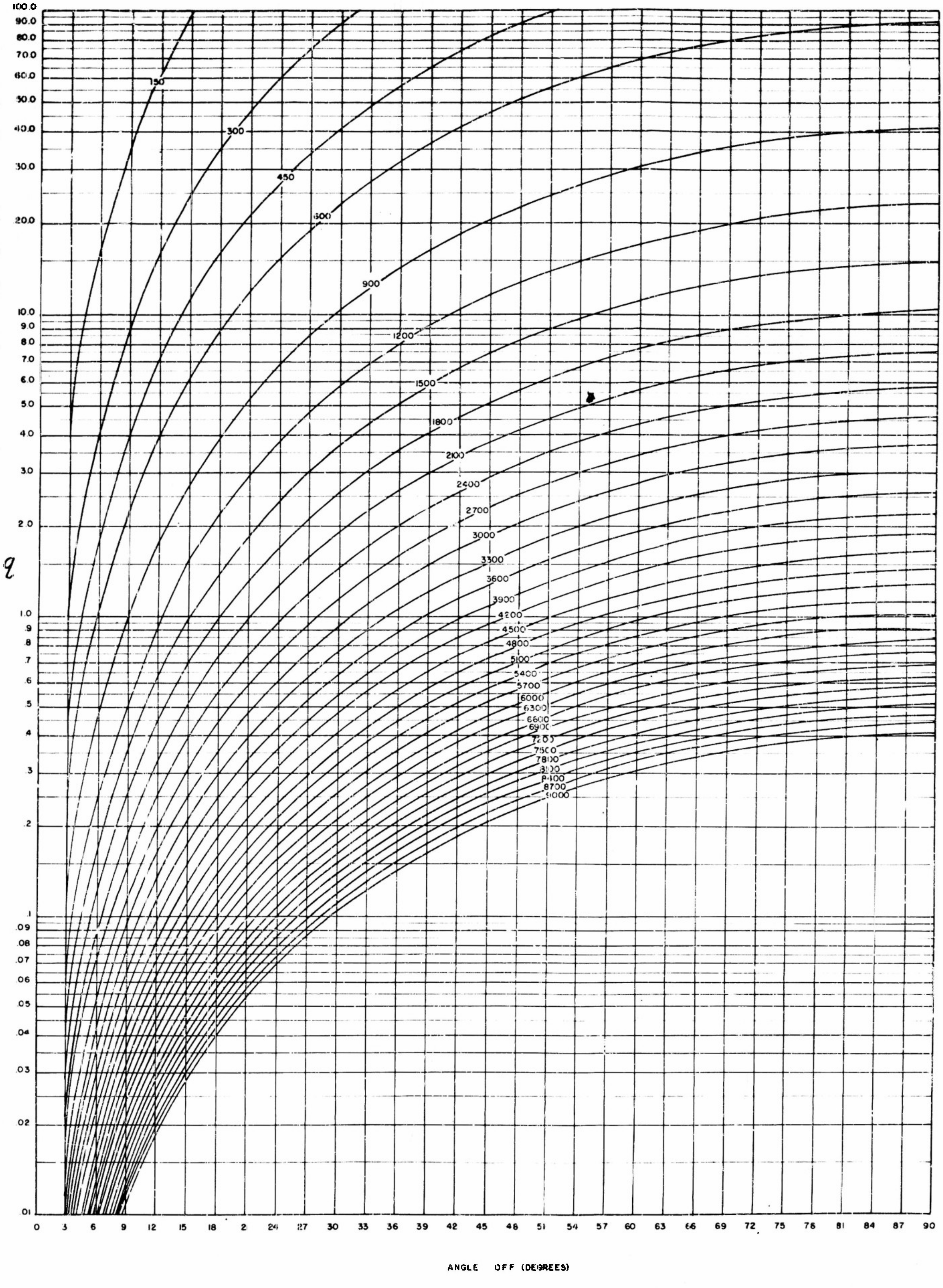


CANBERRA ANGLE OFF GRAPH

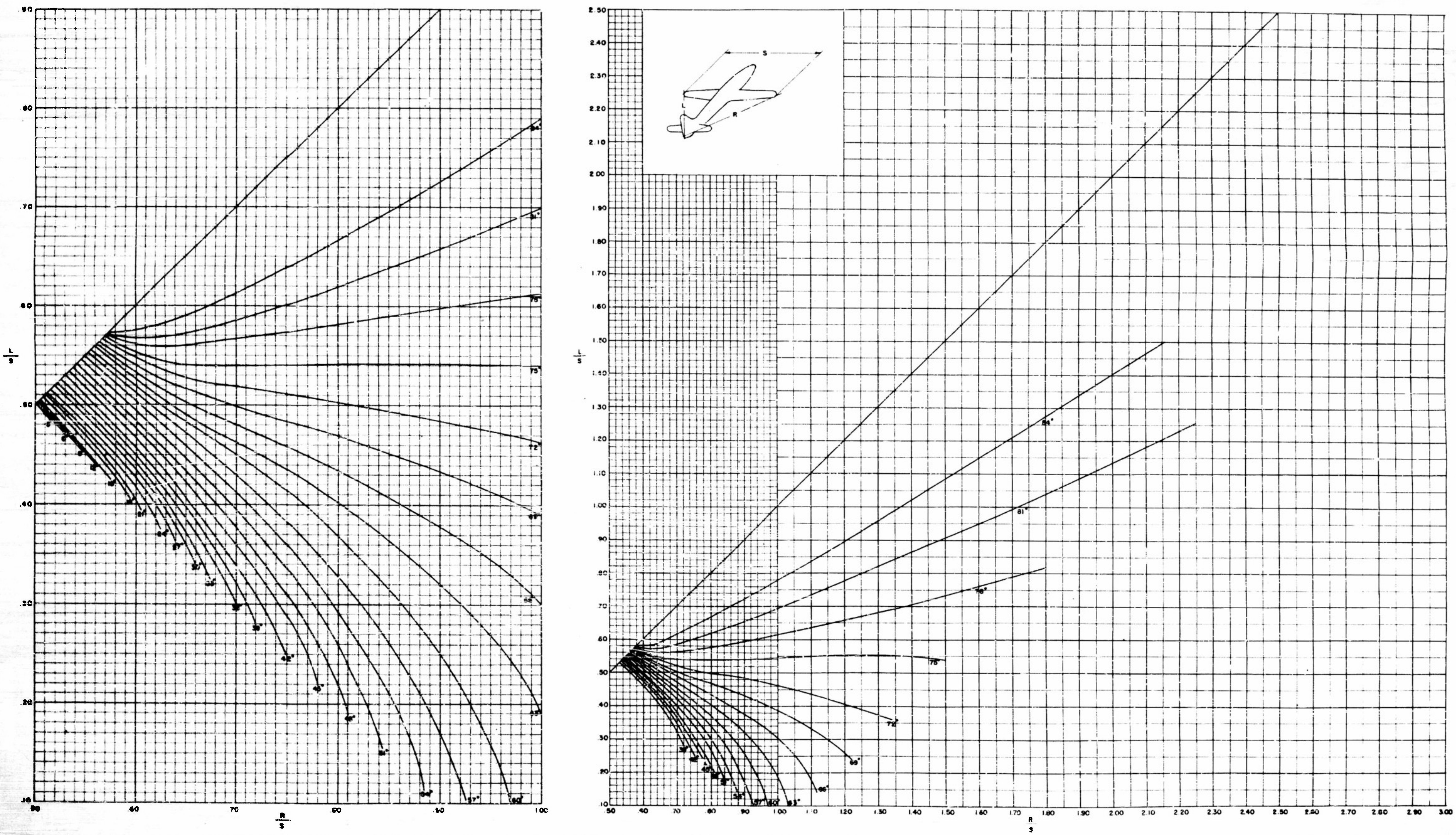




CANBERRA RANGE GRAPH



B-47 ANGLE OFF GRAPH



A.F.-EGLIN AFB, FLA.

B-47 RANGE GRAPH